The LIBERACE+STARS array

L. Phair[1], L. A. Bernstein[2], J. T. Burke[2], J. A. Church[2], R. M. Clark[1], M. Cromaz[1], M. A. Deleplanque[1], M Descovich[1], P. Fallon[1], I. Y. Lee[1], A. O. Macchiavelli[1], M. A. McMahan[1], L. G. Moretto[2], E. B. Norman[2], E. Rodriguez-Vieitez[1], S. Sinha[1], F. S. Stephens[1], M. Wiedeking[1], D. Ward[1]

[1] *Nuclear Science Division, Lawrence Berkeley National Laboratory, Berkeley, California 94720*

[2] *Lawrence Livermore National Laboratory, Livermore, CA 94450*

New features are expected to be observed at the limits of particle stability; such as the spin-orbit interaction dying out because of the weaker density gradient, "true" Cooper (superfluid) pairs at the edge of the continuum, neutron skins and giant haloes, and novel soft-dipole excitations, such as the "pygmy" resonance. Moreover, many aspects of nuclear astrophysics processes (e.g., capture and photo-disintegration reactions) directly involve weakly bound states. At a radioactive beam facility, such as the proposed RIA, weakly bound nuclear matter will be studied by going toward the particle drip lines. At the 88-Inch Cyclotron, parts of this physics can already be addressed through the study of states far above the Fermi surface. These high energy states in stable nuclei can be thought of as the "future" ground states to be studied at radioactive beam facilities.

Improved spectroscopy of weakly bound nuclear matter can be achieved through a combined measurement of particles and gamma rays. The detailed study of gamma rays emitted from states at or near the particle separation energy (as selected by the charged particle measurements) will open a new region of nuclear structure investigations. The general idea is to populate these states via transfer reactions and inelastic collisions and to investigate these states in detail via gamma-ray spectroscopy. This program opens several avenues of research with direct relevance to RIA. This program also provides a natural environment for testing and commissioning the newly completed modules of the GRETINA array.

This past year we have formed a collaboration to install and commission an array of gamma-ray and charged-particle detectors on a dedicated beam line (cave 4C) at the 88-Inch Cyclotron. The collaboration goes by the moniker LIBERACE (for Livermore Berkeley Array for Collaborative Experiments). Presently the array comprises six "clover-type" germanium gamma-ray detectors (see Fig. 1) and a silicon charged-particle detector (called STARS), complete with about 150 channels of electronics and a new data acquisition system. This equipment is now fully operational and the first data taking measurements have recently begun.

Our planned measurements for the first year included specific experiments and reactions aimed at demonstrating feasibility and developing the techniques to (i) track the evolution of states located 6-8 MeV above the Fermi surface in normal nuclei via direct reactions to explore in a novel way the states that define the properties, and hence existence, of drip-line nuclei, (ii) study exotic collective resonances, including the pygmy dipole resonance, using heavy-ion inelastic scattering reactions, (iii) utilize the massive transfer of light beams (e.g. ^{7}Li and ^{9}Be) as an effective "radioactive" beam when a fraction of the projectile undergoes incomplete fusion with the target, and (iv) employ surrogate reactions to infer entrance channel cross sections that cannot be easily measured directly.

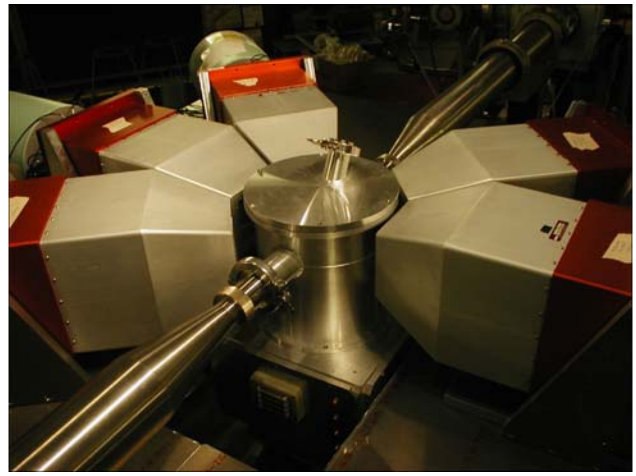

Figure 1. Five (of six) clovers surround a new scattering chamber in cave 4C as part of the LIBERACE setup.

In early 2005 we carried out measurements for each of the topics mentioned above. A brief status is given for (i) and (ii) below. Items (iii) and (iv) can be found elsewhere in this annual report.

(i) The reaction ^{208}Pb(*d*,*p*)^{209}Pb was performed at two beam energies to populate single particle states in ^{209}Pb both near the Fermi surface and at higher excitation energies. States near the surface were identified cleanly with both the charged particles and the coincident gamma rays. The analysis is still underway. We will use the high resolution Ge detectors to characterize the neutron states at high excitation energy.

(ii) A beam of ^{17}O at 380 MeV was used to excite a ^{208}Pb target. The scattered ^{17}O was detected in the STARS array and the gamma rays de-exciting high-lying sates in ^{208}Pb were measured in the Clover Ge detectors. Previous experiments [1] used low-resolution gamma-ray detectors (NaI and BaF_2) and while resonances, in particular the pygmy dipole resonance, were excited no detailed structure was seen in their gamma-rays. We have used high-resolution Ge detectors to attempt to resolve individual states up to and beyond the pygmy region and to establish the decay pathways of these states. The analysis is still underway.

REFERENCES

[1] J. R. Beene *et al*, Phys. Rev. C **39**, 1307 (1989)